Advances in Mask Blank Defect Characterization for EUV Lithography

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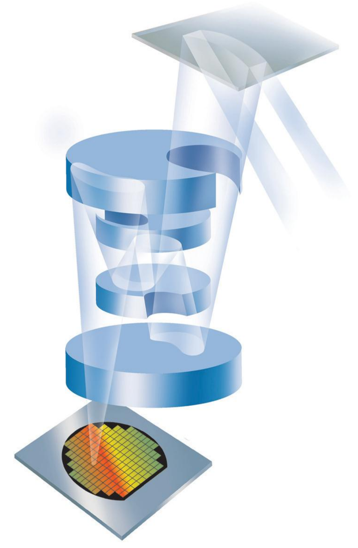
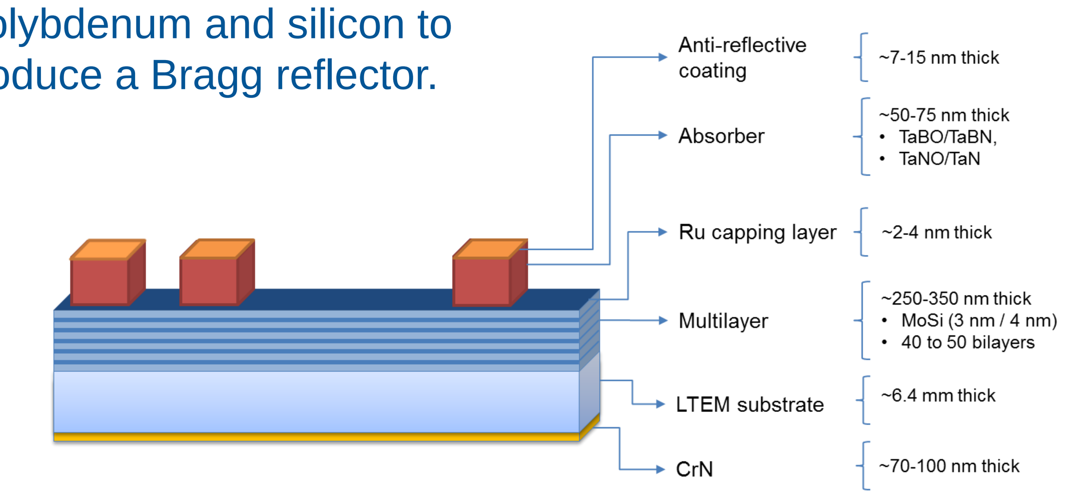
Motivation

- The fabrication of a defect-free mask blank is one of the critical issues limiting the commercialization of extreme ultraviolet (EUV) lithography. Advanced metrology capabilities in the SEMATECH Mask Blank Development Center have assisted in the reduction of defectivity. Metrology tools in the MBDC support this effort by detecting defect location, size, and composition on the blank, providing valuable information leading to defect sources.
- The use of advanced metrology tools including transmission electron microscopy (TEM) and Auger electron spectroscopy (AES) has assisted in the progression of EUV mask blank defect reduction by providing failure analysis capability for sub-100 nm defects. SEMATECH is evaluating new atomic force microscopy (AFM) techniques for non-destructive defect characterization.
- Recent defect characterization results from the TEM and Auger systems will be shared and the current status of the AFM evaluation will be discussed.

EUV Mask Blank Overview



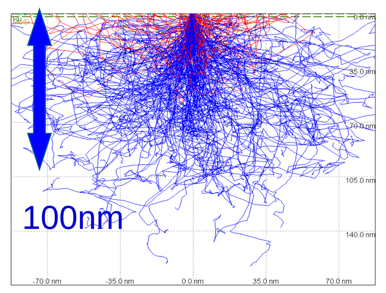
- A mask blanks are made with a low thermal expansion substrate coated with a multilayer composed of molybdenum and silicon to produce a Bragg reflector.

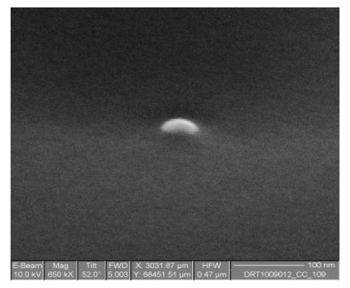


- Defects in or on mask blanks cause a change in the phase or amplitude of the reflected EUV light. Defects can be sorted into two types: pits and particles.
  - Pits can be found on the substrate from CMP processes or on the multilayer from surface cleaning damage. *Growth on pit-type defects result in destructive interference of the reflected light causing intensity change – phase defect.*
  - Particles can be found on the substrate, in the multilayer, or on the surface of the multilayer. Common particle contributors are chamber, plasma, handling, incoming substrates, handling and the vacuum system. *Particles in the multilayer can result in both amplitude change and destructive interference causing intensity contrast in the reflected light – phase or amplitude defect.*

Current Metrology Limitations

- Scanning electron microscopy:
  - The I interaction volume of EDS limits the size of defects for compositional analysis
  - Sample preparation for smaller defects becomes challenging

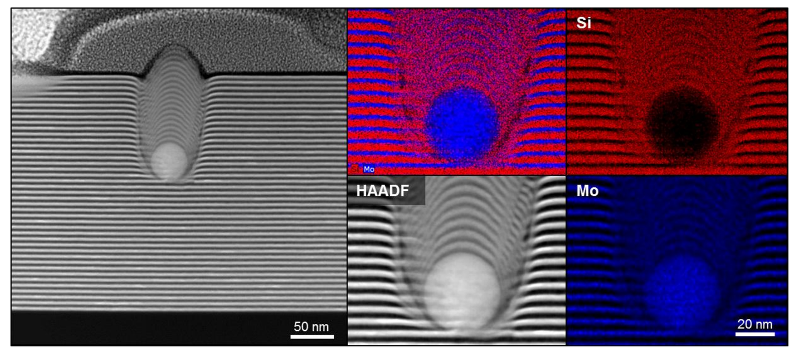




- Conventional AFM used in defect review cannot provide defect composition data

Transmission Electron Microscopy Results

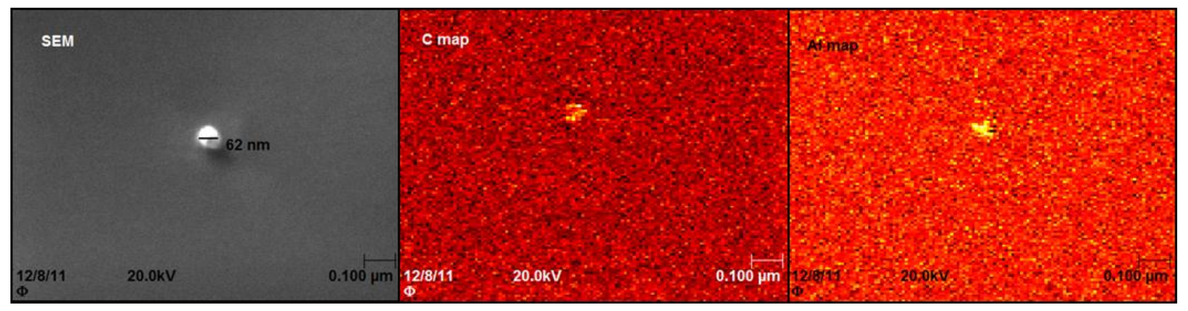
- TEM has become an integral tool for failure analysis of EUV mask blank defects, and energy dispersive X-ray spectroscopy (EDS) in STEM has proven to be a valuable technique for the elemental identification of sub-100 defects.
- Recently SEMATECH has received an "in-field" upgrade to the EDS detection system on its C_s-corrected, monochromated FEI Titan S/TEM 80-300 from the RTEM Genesis system to the SuperX system.
- In addition to EDS analysis, electron energy loss spectroscopy (EELS) can be performed. EELS proves to yield more material information about a sample; however, the technique is much more challenging in both sample preparation and spectrum acquisition.
- S/TEM is supporting many defect mitigation projects including substrate smoothing activities, deposition modeling support, and defect printability studies.



The ion source extractor grids are composed of Mo material, and Mo spherical particles can be generated from the grids during high power plasma causing degradation in grids. Shorting between the source grids causes arcing and generates spherical Mo particles from the high thermal load. Above is a 45 nm Mo spherical defect that fell during the deposition process.

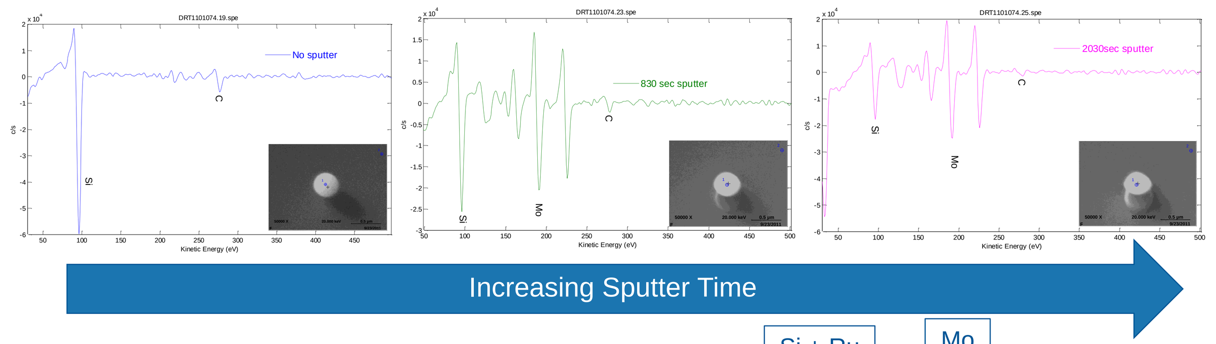
Auger Electron Spectroscopy Results

- AES provides an excellent surface analysis technique for identifying the composition of small EUV mask blank defects as evidenced by early results of the SMART-II tool.

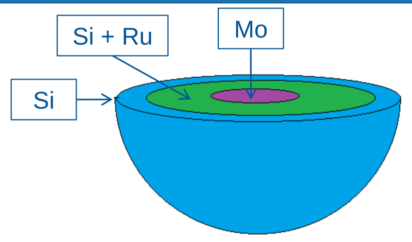


Above: SEM image and elemental maps by AES identify a 62 nm defect on a quartz substrate as carbon and aluminum.

- Embedded defects near the surface of the blank can also be analyzed with AES using depth profiling.

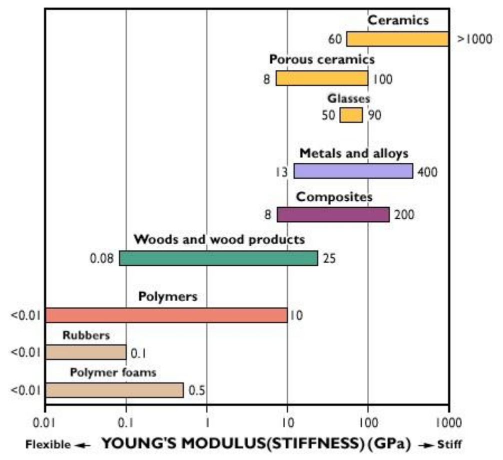


A spherical defect fell during an experimental deposition, and the composition of the core was unknown. Above: Spot profiles at each sputter time. Right: Illustration of defect composition. As before, the spherical Mo defect from the source extractor grid fell during deposition.



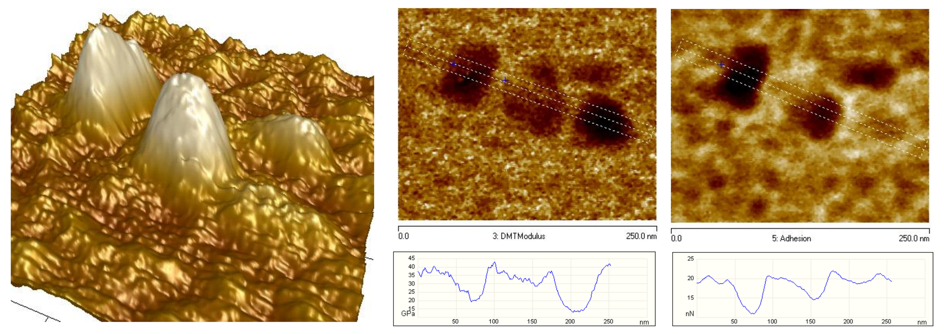
Atomic Force Microscopy Results

- Peak Force Nano-Mechanical Quantification (PF-QNM) in AFM can be used to obtain mechanical data (Young's modulus and adhesion) of a defect in addition to topography and size information.
- PF-QNM cannot yield composition information, but with the creation of a defect library, defects can be categorized into general material types based on the mechanical data.
- The technique is limited to surface defects only allowing for non-destructive analysis of cleaning and handling defects.
- Preliminary evaluation has been completed on a substrate, and more experiments are planned for mask blank defects.



Above: Chart of relative Young's modulus measurements for various types of material

Right to left: 3D topography scan of 4 small particles ranging from 0.2 to 1.5nm in height and ~40nm wide, Young's modulus, and adhesion measurements showing that the defects are 2x-3x softer and 20%-50% less adhesive than the substrate



Summary

- Accurate characterization of EUV mask blank defects can lead to mitigation solutions. Two promising techniques for small defects are TEM and AES.
- The FEI Titan 80-300 S/TEM received an upgrade to its existing EDS detection to the SuperX, greatly improving the analysis capability for sub-100 nm defects.
- AES is providing valuable composition information for EUV mask blank defect reduction efforts.
- PF-QNM is under investigation for a non-destructive characterization method.

Acknowledgements

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